SHALLOW MARTIAN "SILLS": INTRUSIONS OR EXTRUSIONS? Tracy K.P. Gregg[1] and Peter H. Schultz[2], [1]Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA 02543; ph: (508) 289-2615; e-mail: tgregg@whoi.edu, [2]Department of Geology, Box 1846, Brown University, Providence, RI 02912.

Thick (>30 m) lava flows with steep flow fronts and "festooned" or "folded" surfaces are widely distributed on Mars. Flow thickness, surface textures, and crenulated margins are at odds with a mafic (or ultramafic) composition. These flows are typically associated with an overlying , etched deposit >10-25 m thick that is apparently being actively modified by aeolian processes. Fluvial channels are also common near these textured flows. Emplacing mafic lavas beneath an ice-rich, fine-grained deposit can explain the morphology of these flows as well as their geologic associations.

Thick, ridged lava flows occur south and northwest of Elysium Mons, southwest of Olympus Mons, and in the Amazonis region [1, 2, 3], and are associated with an etched, friable deposit >25m thick (based on shadow measurements of pedestal craters found within the deposit) with a feathered margin (Fig. 1). Its etched morphology suggests that the deposit is being modified and locally removed by aeolian processes, indicating that it is composed of fine-grained material. The precise origin of this material is unknown, but it has been called an ignimbrite [4], ancient polar deposits [5] and an aeolian deposit of unspecified origin [6, 7]. We propose that this friable deposit, regardless of origin, was present before the eruption of the textured lavas, and that the lavas were emplaced beneath it. Observations and results from numerical models further suggest that the deposit contained intergranular ice during the eruption. This scenario has broad implications for the stratigraphy of a large region on Mars.

Terrain around the textured lavas and their associated deposits contains braided channels and stream-lined islands. Some channels may also have been modified by aeolian processes: locally, channel floors are topographically higher than the surrounding terrain. This is attributed to preferential removal (probably by aeolian processes) of relatively fine-grained material surrounding the channels, whereas channel floors are "armored". either by coarser stream-carried material or immobilized silt-size duricrust [e.g., 5]. Thus, the textured lavas were emplaced in an environment affected by fluvial and aeolian depositional and erosional processes.

If the ridged texture of these lavas is caused by folding of a surface crust during emplacement [2, 3, 8, 9], then fold dimensions and flow thickness indicate that the lavas were too viscous to have mafic or ultramafic compositions--although flow volumes and lengths strongly suggest a fluid lava, and it is generally believed that martian lavas are mafic or ultramafic [10]. This apparent paradox can be resolved by emplacing (mafic) lavas *beneath* an ice-rich, fine-grained deposit. The deposit would cause the flow surface to cool more quickly--and generate a thick solid crust more rapidly--than on an identical flow emplaced on

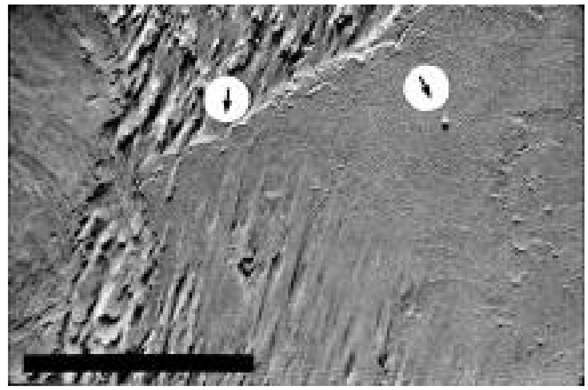

Figure 1. Textured lava flow emerging from beneath fine-grained deposit SW of Elysium Mons. Note steep flow front and pedestal crater (arrows). Bar is 10 km.

the martian surface. Enhanced cooling could generate a lava flow with large-scale surface folds and thick, bulbous or crenulated margins [3].

Observations of terrestrial basalts flowing beneath (or "burrowing into"; [11, 12]) wet sediments reveal that the flow morphology is different beneath the sediments. Once beneath the sediment, terrestrial basalt flows became thicker and more bulbous with a more subdued fine-scale (<100cm) surface texture. Beneath sediments, basalt appears to advance through a series of long bulbous "fingers" (elongate parallel to the flow direction) which coalesce to create a single surface marked by subtle valleys where the separate lava "fingers" joined, resulting in a larger-scale surface morphology. This is due to different cooling mechanisms: a wet deposit removes heat via phase transition of ice to water or steam, thermal convection of the water, thermal radiation, and thermal conduction through the solid grains of the deposit. Subaerial flows are cooled only by radiation and atmospheric convection.

Results from numerical models reveal that basalt flows may produce substantially different morphologies when intruded beneath an ice-rich, fine-grained deposit than when emplaced on the martian surface. Specifically, models can predict the rate of crust growth for identical lava flows emplaced in different environments. By comparing these results to laboratory simulations [13, 14], we can estimate how the flow morphology should be affected. To constrain the rate of crust growth, we use a range of parameters for the fine-grained deposit. The relative amounts of particles, water ice, and void space within the deposit can be estimated with assumptions for a bulk density of 500 kg/m^3 for the fine-grained deposit, and a density of ~2200 kg/m^3 for the individual particles (approximating a weathered basalt [15]). The heat flux at the flow surface then can be calculated using the following equation:

$$F_{rad} + F_{conv} + F_{cond} = rseT^4 + (1\text{-}p\text{-}w)kT + wr_w c_w g\,(gr_w a_w D_w^2)^{1/3}\, h_w^{-1/3}\, T^{4/3}$$

in which p is the fraction of the overlying deposit represented by solid grains, s is the Stephan-Boltzman constant, e is emissivity, T is the temperature of the flow surface, w is the fraction of the deposit represented by water ice, k is thermal conductivity, r is density, c is heat capacity, g is a constant ~0.1 [13], g is gravity, a is thermal expansion, D is thermal diffusivity, h is kinematic viscosity, and the subscript "w" represents water ice. Including only 0.5 vol% ice significantly increases the rate of lava crust growth (Fig. 2).

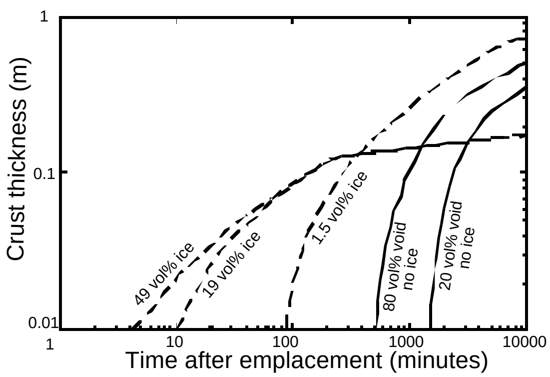

Figure 2. Rate of crust growth on martian basalt beneath a dry and ice-rich deposit with various amounts of ice and void space. The addition of only 1.5 vol% ice increases the rate of crust growth dramatically.

Folding analyses [1, 8] indicate that thicker crusts generate longer-wavelength folds on the surface of a lava flow. Emplacement of lavas beneath an ice-rich dust layer enhances crust growth. Consequently, a flow which might normally produce a smooth sheet flow could instead generate a folded texture. This inference is consistent with results obtained through laboratory experiments in which polyethylene glycol wax is extruded into a tank filled with cold sucrose solution [13, 14]. Geologic observations also suggest that these textured lavas on Mars were emplaced beneath an ice-rich deposit. First, relict deposits are currently superimposed on some of the textured lavas and the region is noted for its radar-absorbing properties [16]. The morphology of craters observed on the surface of the deposit suggest that the deposit may have been at least 15-25 m thick--sufficient for altering the cooling mechanism of a lava flow. Second, the presence of channels around these lavas indicates that abundant water was once present in these areas, yet such channels do not incise the lava flows.

We cannot determine if the lavas were erupted beneath the friable deposit, like a shallow intrusion, or were erupted beyond the limits of the deposit and burrowed into it. However, the preponderance of evidence strongly suggests that the fine-grained deposit was present before the textured, thick lava flows were emplaced.

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